Rule 1110.2 Technology Demonstration Project

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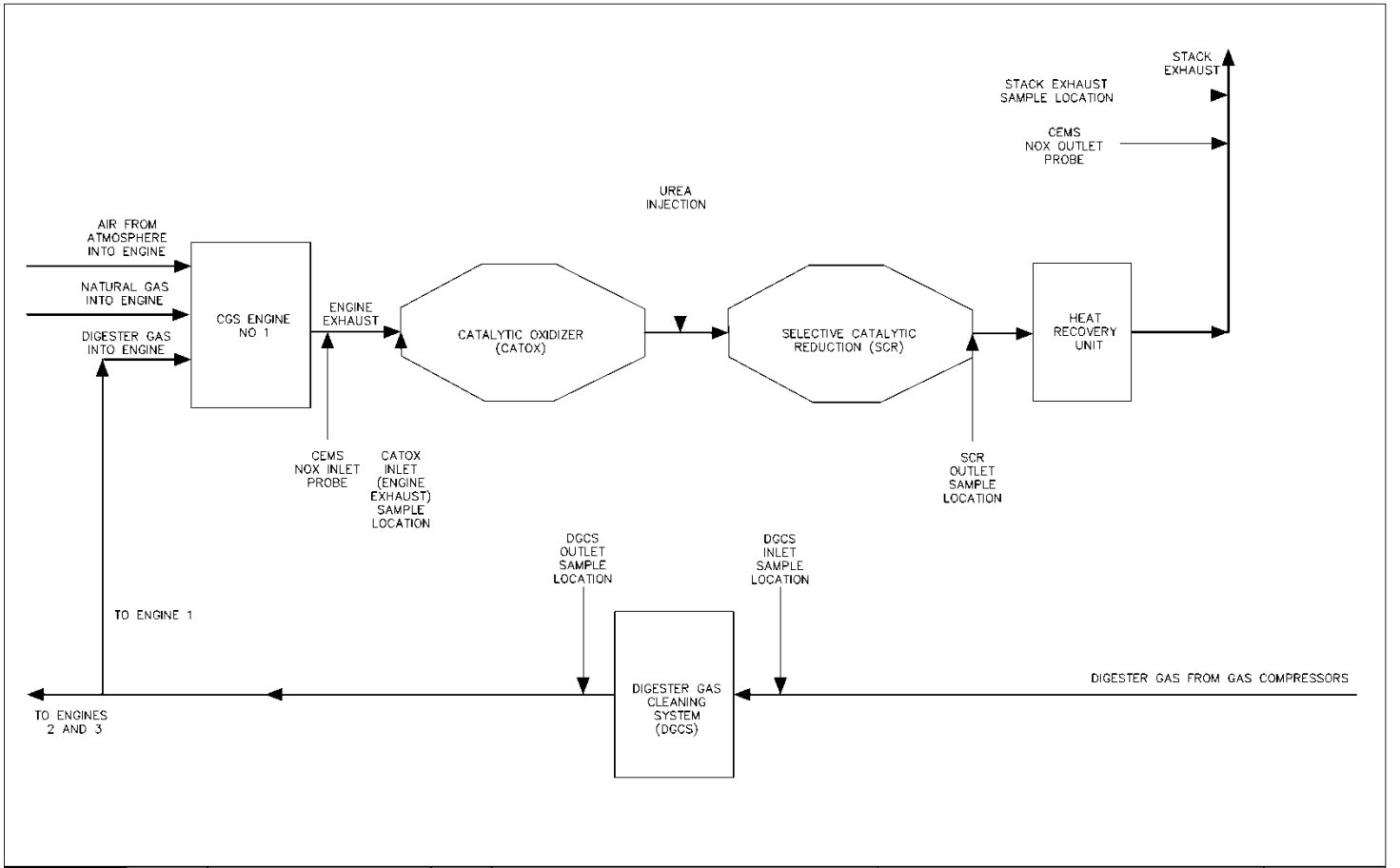
Part I: Project Description & Report Highlights

Process Flow Diagram

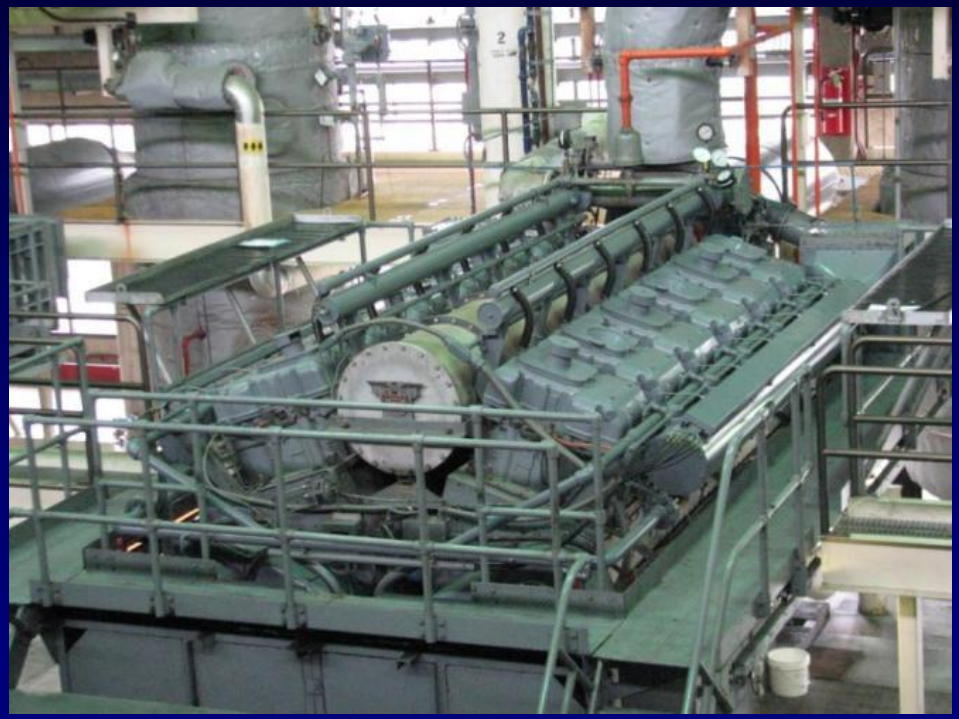


Pre-Engine Digester Gas Cleaning

- Single fixed carbon bed
- Applied Filter Technology
- 9,900 lbs media capacity
- 8 feet high

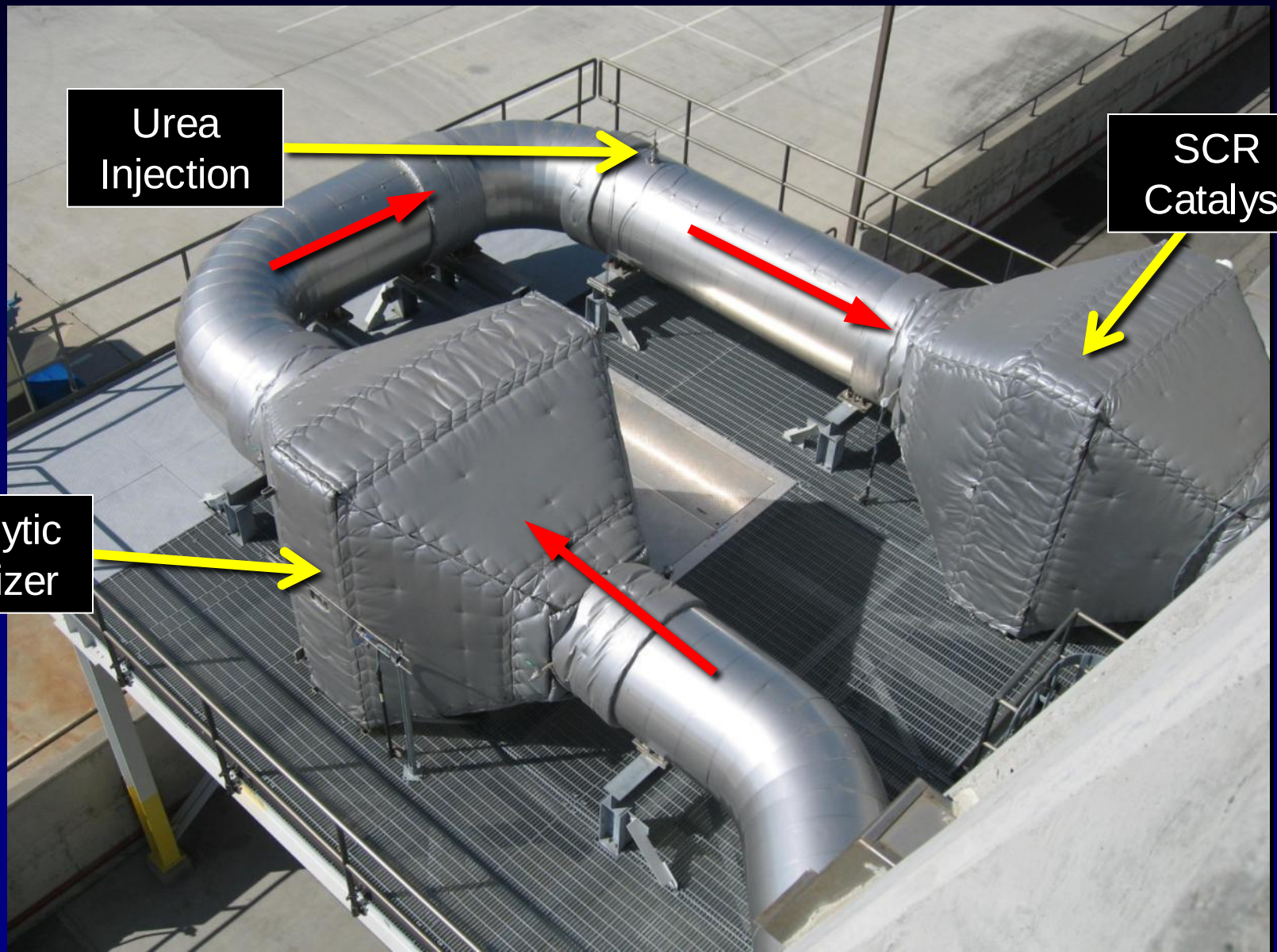
NOTE: Digester gas flows from low pressure gas holder to gas compressors, followed by a heat exchanger to remove moisture (already in service prior to project) before entering the carbon bed shown here.

Demonstration Engine



- Cooper-Bessemer V-12
- In operation since 1992
- 3471 hp
- Lean burn
- Driving 2500 kW generator
- Heat recovery steam generator
- NOx and CO CEMS

Catalytic Oxidizer/SCR System



SCR Urea Injection Control Panel and Urea Tank

Current Status of Project

- Demonstration monitoring period ran from April 1, 2010 to March 31, 2011
- Final report submitted to SCAQMD in July 2011
- Currently operating under Experimental Research Permit
- OCSD intends to renew permit to continue research on this system

Site-Specific Cost Considerations

1. Space constraints for equipment
   - Able to install gas treatment in optimal location
   - Platform was constructed to create footprint for catalysts
   - Equipment for compression & gas chilling in place prior to demonstration project
2. NO_X inlet analyzer for ammonia slip calculation

OCSD Plant No. 1 Digester Gas Composition

	Min. (%)	Max. (%)	Avg. (%)
CO_2	25.5	40.1	33.9
CH_4	53.7	62.6	58.7
N_2	0.9	5.1	2.2
O_2	0.1	1.4	0.6

Reduced Sulfides in OCSD Plant No. 1 Digester Gas

Compound	DGCS Inlet		
	Min. (ppmv)	Max. (ppmv)	Avg. (ppmv)
Hydrogen Sulfide	14.690	31.870	26.381
Carbonyl Sulfide	.010	.028	.019
Methyl Mercaptan	.048	.081	.062
Ethyl Mercaptan	.189	.304	.258
Dimethyl Sulfide	.006	.017	.012
Carbon Disulfide	.004	.009	.006
n-Propyl Thiol	.454	.679	.581
iso-Propyl Thiol	.214	.416	.344
Dimethyl Disulfide	ND	ND	ND
Isopropyl Mercaptan	.250	.250	.250
n-Propyl Mercaptan	.320	.320	.320

Siloxanes in OCSD Plant No. 1 Digester Gas

Compound	DGCS Inlet		
	Min.	Max.	Avg.
	(ppmv)	(ppmv)	(ppmv)
Hexamethyldisiloxane (L2)	<MDL	<MDL	<MDL
Hexamethylcyclotrisiloxane (D3)	.010	.017	.012
Octamethyltrisiloxane (L3)	.010	.019	.014
Octamethylcyclotetrasiloxane (D4)	.369	1.6	0.704
Decamethyltetrasiloxane (L4)	.073	.170	.121
Decamethylcyclopentasiloxane (D5)	1.300	14.000	5.371
Total Siloxanes	**.919**	**15.700**	**5.452**

Gas Cleaning System Performance

- Both H2S and siloxanes monitored. H2S used as indicator of general contaminant breakthrough.
- Carbon media was changed out 3 times during demonstration period (data below shows system outlet concentrations):

  146 mmcf gas treated (2 ppm H2S, 0.248 ppm siloxanes)

  169 mmcf gas treated (2.5 ppm H2S, siloxanes <MDL)

  157 mmcf gas treated (1.76 ppm H2S, siloxanes <MDL)

Cost Effectiveness – Annualized Cost

Total Capital Cost* (2009 dollars) = $ 2.3 million

Annualized Capital Cost (4% annual, 20 yrs) = $ 168,400

Annual O&M Cost per engine** = $59,000

Total Annualized Cost per engine $227,300

*Total capital cost includes

- Equipment (catalysts, gas cleaning system, inlet NOx analyzer)
- Labor & contractor costs
- Project design & engineering

**Annual O&M savings due to reduced maintenance is $43,500 per engine and reduced emission fees is $9,100 per engine

Cost Effectiveness – Per Ton of Removal

Scenario 1: permit limit to R1110.2 limit

- NOX reduced from 45 ppm to 11 ppm
- VOC reduced from 209 ppm to 30 ppm
- CO reduced from 2000 ppm (rule limit) to 15 ppm
- Cost Effectiveness: $8,000 per ton of NOX and VOC removed and $640 per ton of CO removed

Scenario 2: actual exhaust (source test) emissions to R1110.2 limit

- NOX reduced from 31 ppm to 11 ppm
- VOC reduced from 97 ppm to 30 ppm
- CO reduced from 371 ppm to 15 ppm
- Cost Effectiveness: $17,600 per ton of NOX and VOC removed and $3500 per ton of CO removed

Part II: Monitoring Results & System Performance

Emissions Levels Achieved, ppmv

Pollutant	Engine Exhaust	Stack Outlet Average (Range)	Rule 1110.2 limit
NOx	31	7.2 (0.8 to 21.8)	11
CO	452	7.5 (4.0 to 42.2)	250
VOC	97	3.6 (0.73 to 5.42)	30

15-minute averages. Validated data only (excludes exceedances during engine start-up (30 minutes) and due to operational issues/systems adjustments).

CO CEMS Data

- CEMS data showed range of 4.0 ppm to 42.2 ppm, with average concentration 7.5 ppm
- CO reduction of 96% consistently seen using portable analyzer (no inlet CO analyzer)
- No data above the 1110.2 limit
- Data points used were 15-minute averaging period
- OCSD permit limit is 590 ppmv

VOC Results

- NMNEOC analyzed using SCAQMD Method 25.3
- Five sampling events
- Average concentration: 3.58 ppmv
- Range of results was 0.73 ppm to 5.42 ppm
- Noticeably below the R1110.2 limit of 30 ppmv
- Uncontrolled concentration is 97 ppmv

NOX CEMS Data

CEMS data showed range of 0.8 ppm to 21.8 ppm, with average concentration 7.2 ppm (15 minute average)

NOX outlet concentrations > 11 ppm occurred when:

- Engine had just come online
- Ratio of natural gas to digester gas in fuel blend increased
- Engine loads exceeded the loads mapped during the urea injection system configuration
- Abnormal operating conditions occurred (turbocharger waste gate malfunction, etc)
- Adjustment of the urea injection system was made by vendor

Occurrences of NOx > 11 ppm

Number of 15-minute periods with NOX > 11 ppm		% of Total Data Points
Engine start-up (30 minutes)	63	0.3
Operational Issues (atypical operating cond.)	678	3.2
System Adjustment	17	0.1
Increase in NG Fuel Composition	44	0.2
High Load (>100%)	59	0.3
Other	79	0.4
Total	940	4.4
Engine Operating Periods (15-minute averages)*	21285	

*Equivalent to 5321 operating hours

Average and Range of NOx Results > 11 ppm

Parameter	NOx Inlet (ppmvd)	All NOx Stack Exhaust (ppmvd)	Validated NOx Stack Exhaust (ppmvd)
Average	30.68	7.53	7.16
Minimum	10.72	0.80	0.80
Maximum	64.70	45.23	18.69
Number NOx Stack Exhaust > 11 ppmvd	N/A	940	182*
Percent of total operating time > 11 ppmvd	N/A	4.4%	0.9%

*Sum of increased NG, high load, and "other" events (from previous slide)

SCR Performance Limitations

- Performance of SCR affected by ratio of DG/NG, responsiveness to startup/shutdown, and load variations due to gas availability
- Urea injection system was mapped for a fuel blend of 95% or more digester gas (typical OCSD fuel blend)
  - Control system can only be programmed with one set of mapping (such as engine load to urea injection rate)
  - Cannot adjust for both load variations and fuel blend variations.

Thoughts on Ammonia Slip

- Experimental research permit NH_3 limit = 10 ppmv
- Measurement methodologies produced widely different results at the same time:
  - Draeger tubes: NH_3 below MDL
  - Modified SCAQMD Method 207.1: NH_3 = 0.5 ppmv
  - Theoretical calculation using CEMS inlet & outlet NOX data produced results three to 10 times higher than SCAQMD method

Conclusions

- It is difficult to maintain a targeted NOx limit at the stack exhaust using the SCR system (where urea injection rate is based on engine load and not on inlet NOx concentration).
- The excursions over 11 ppm may indicate that this limit is too conservative.
- Using the 15-minute block average for compliance may be too restrictive. A longer averaging period, and allowing a limited number of excursions, may be warranted.

Questions?

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